17th ICCRTS
"Operational C2 Agility"

Mission Effectiveness: Proposed Nth Order Taxonomy

Topic #1: Concepts, Theory, and Policy

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14. ABSTRACT
Within net-centric operations, military commanders need to plan and assess operations in the context of a ?complex endeavor.? Potential courses-of-action (COA) must take into account impacts dealing with: political, diplomatic, social, economic as well as military, information and infrastructure. When considering cyber operations, military timelines have been reduced by several orders of magnitude to keep pace with operations being conducted within a global cyberspace environment. Suggested is a 0th ? 9th order-effects taxonomy to give a more robust complete and consistent ?effects? analysis of potential COAs. This taxonomy can be sub-divided into three groups: 1) ?tactical level effects;? local area around the target; 2) ?operational level effects;? region surrounding the target; and, 3) ?strategic level effects;? global nature of the target. Of note is that effects within the cyber domain can achieve ?global effects? far faster than other domains due to its unique ?borderless? nature. For each ?layer? of effectiveness, metrics are used to ?assess/plan? when considering the ?desired effects? within a complex endeavor. Performing analysis on nth order-effects is primarily qualitative; therefore a ?subjective logic? approach using belief, disbelief, and uncertainty as sub-divisions was used to evaluate Detrimental to Operations, Unacceptable, Acceptable, Very Acceptable, and Significantly Acceptable to Operations.

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Abstract

Within net-centric operations, military commanders need to plan and assess operations in the context of a "complex endeavor." Potential courses-of-action (COA) must take into account impacts dealing with: political, diplomatic, social, economic as well as military, information and infrastructure. When considering cyber operations, military timelines have been reduced by several orders of magnitude to keep pace with operations being conducted within a global cyberspace environment. Suggested is a 0^{th} – 9^{th} order-effects taxonomy to give a more robust, complete and consistent "effects" analysis of potential COAs. This taxonomy can be sub-divided into three groups: 1) "tactical level effects;" local area around the target; 2) "operational level effects;" region surrounding the target; and, 3) "strategic level effects;" global nature of the target. Of note is that effects within the cyber domain can achieve "global effects" far faster than other domains due to its unique "borderless" nature. For each "layer" of effectiveness, metrics are used to "assess/plan" when considering the "desired effects" within a complex endeavor. Performing analysis on nth order-effects is primarily qualitative; therefore a "subjective logic" approach using belief, disbelief, and uncertainty as sub-divisions was used to evaluate: Detrimental to Operations, Unacceptable, Acceptable, Very Acceptable, and Significantly Acceptable to Operations.

Introduction

At issue today is how to measure the effectiveness (or non-effectiveness) of particular event(s) that occur during military engagements (integration of air, space and cyberspace). What is even more challenging is to determine metrics for Nth-Order effects; not to mention that there is no agreed upon definition for an Nth-Order effect. It is no surprise that cyber operations have become co-equal with other operations in importance and criticality. In 2006, the Secretary of the Air Force added a third arm to the Air Force Mission: that of cyberspace. Given the growing importance of the role of cyberspace within the Air Force, a sound strategy for achieving reliable, survivable, assured and continuous cyber operations has become paramount within the 21^{st} century. In fact, cyber operations have the potential to become an influential power provided by the Air Force. Cyber operations can be thought of as the third leg of a "C2 Triad" (Air and Space being the other two). By adding this third leg, fundamental methodologies, such as Effects Based Operations (EBO) can be greatly enhanced.

The networks and information systems that are being constructed today are extremely complex. An adversary cyber attack against a network could have cascading and devastating effects on other portions of the information enterprise. To defend against a network wide attack, it is imperative that we know what is on our systems and their composition. We need to know what computers we have, what applications are running, what vulnerabilities exist and what networks

are related to other networks. Only when armed with this type of information can we possibly adapt our countermeasures and protection procedures to counter an adversary.
When considering cyber operations, military timelines will have to be reduced by several orders of magnitude in order to be able to keep pace with operations being conducted within a global cyberspace environment. Timelines to conduct a military operation have significantly been reduced from weeks-months to minutes-seconds. For example, in the mid-1990s, the then CSAF Gen Jumper embarked on the goal of performing "sensor-to-shooter" operations in "single-digit-minutes." This was no easy task. The inter-relationships of data, information, awareness, understanding and decision making along with the corresponding actions is quite complex. Imagine conducting a "sensor-to-shooter" operation from when a sensor "detects" a target (t_0) to when the target is neutralized (t_n); all this has to occur within "single-digit-minutes" or a maximum of 599-seconds! Since multiple "entities"[1] are involved there are different timelines for each entity; thus to achieve "shared awareness" or "shared understanding" one has to wait for the "slowest entity."

Within the context of net-centric operations, there is a series of timelines that one needs to consider when conducting operations. Appendix A provides a graphic and a table illustrating these relationships.

Now consider today, where the "sensor-to-shooter" resides in the cyber domain. This timeline needs to be conducted in milli-seconds-to-seconds-to-minutes! These are the fundamental issues that need to be considered when dealing with net-centric operations in the composite of the three domains (air, space, cyber).

Phases of Conflict

The Phases of Conflict (Figure 1) that are used typically are applied to the air domain of military operations. However, military engagements must take into account an integrated view of air, space and cyberspace operations. For example, Figure 1 illustrates that within air, space and cyberspace the AF goals of Global Vigilance, Global Reach, and Global Power have a place in all the stages. Naturally, the levels of engagement will be different for each of the seven phases. For example, cyber engagements could be higher during the periods of peace and crisis and act as neutralizers with the goal of not moving into Operations Other than War (OOTW) or war itself. During recovery and reconstitution, military engagements will be more defensive in nature to restore and recover military air, space and cyberspace systems.

[1] An entity can be an individual, a team, an organization or a software algorithm, depending on the application.

Figure 1: Phases of Conflict[2]

Some examples of the application within the cyber domain:

a) *Global Vigilance:* Utilizing the cyber domain provides a significant ability to continuously monitor world events and to focus on anything, anywhere and at anytime. Extending Global Vigilance into the cyber domain can perform missions in all the phases; however, the focus differs depending on the phase of conflict.

b) *Global Reach:* Extending into the Cyber Domain, the use of Global Reach can perform missions in all phases. Naturally, the intensity changes depending on the phase. One mission might be to "follow the money" of a suspected adversary. The result would be to: 1) freeze the assets, and, 2) find the adversary (anywhere, anytime). The goal would be to minimize the chances of escalating to the next phase. Global Reach can be applied to defensive cyber operations as well. This would entail the ability to detect an intrusion (Global Vigilance), reach out and touch them (Global Reach) and then negate their actions (Global Power).

c) *Global Power:* Within the Cyber Domain, this would be the application of non-kinetic power versus kinetic applications (which is the focus of the current definitions). Global Power can be applied to all phases of conflict in the form of D5 (Disrupt, Degrade, Deny, Deceive, and Destroy). Naturally, the focus changes depending on the phase. In OOTW and War, this complements the traditional kinetic effects to achieve the desired outcome. Global Power also exists in defensive operations (which are applied to all phases of conflict) as the ability to rapidly negate any and all cyber threats in conjunction with Global Reach to go out and D5 an adversary.

[2] Data does not represent actual values. They are included for illustrated purposes only.

To make this more complex within the 21st Century, the military mission space encompasses a wide range of operations (see Figure 2), which includes not only military operations, but civil operations as well. To achieve success requires 1) an effects based approach to operations where the effects that need to be considered include not only military effects, but social, political, and economic effects, and 2) the ability to work effectively in coalition environments that include not only other militaries but also other government entities, international organizations, businesses, and a variety of non-governmental and private volunteer organizations. (Alberts, 2007: 2) Therefore, a cyber engagement is analogous to either an air or space engagement. (Phister, 2011)

Span of a Complex Endeavor

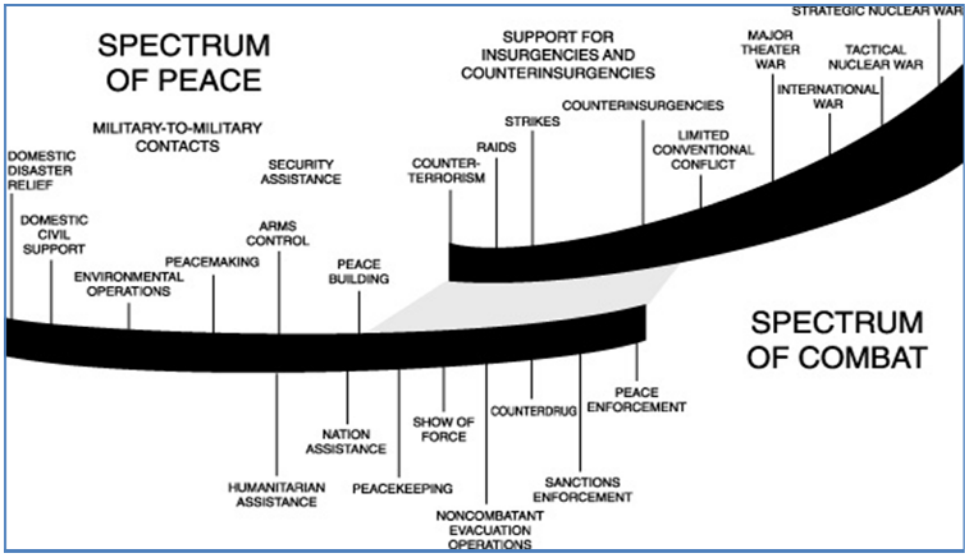

Figure 2: Span of a Complex Endeavor

The work that was accomplished under a NATO sponsored "C2 Agility" working group (SAS-065) was published under the CCRP Publication umbrella (Alberts, 2007: 122). Figure 4 summarizes the space that has to be considered when dealing with a complex endeavor.

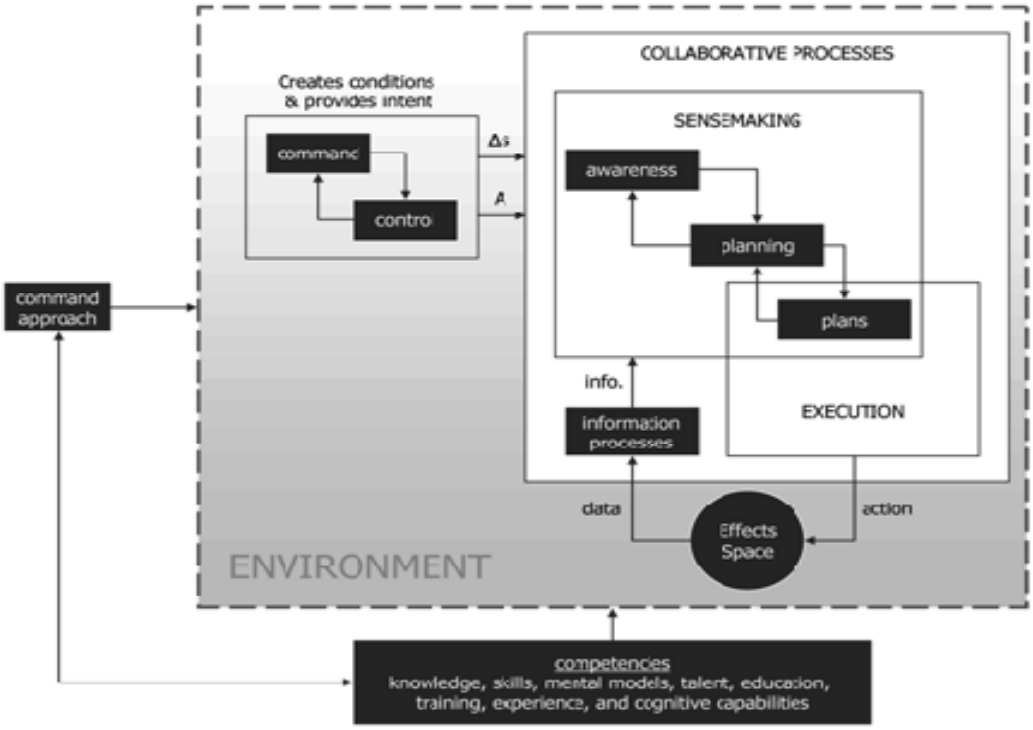

Figure 3: Planning in the Context of C2 and Operations

Conducting operations within the Cyber Domain is complex; especially when one considers the compressed timelines and the global players (military, civil, etc).

Effects Based Operations

Basically, effects-based operations are coordinated sets of actions directed at shaping the behavior of friends, foes, and neutrals in peace, crisis, and war. (Smith, 2002: xiv) The concept of effects-based operations is a broad framework which includes ideas like "nodal targeting" and "attrition-based operations," but which offers the scope and flexibility to do much more: to look at military operations in peace, crisis, and war *(plus all the other phases),* and to do so in the context of a cohesive overall national political, economic and military effort. (Smith, 2002: 104)

A key factor that emerges during the planning and assessment portions of a military operation is the effects that can be achieved (or not achieved) given the stated Command intent. Within this military concept, effects-based operations translate into "What are the effects that will occur given this particular COA[3]?" Additionally, this must take into account "Complex Endeavors" since the Air Force does not "Fly, Fight and Win" singularly, but rather in a multi-service, coalition environment.

[3] COA = Course-Of-Action or Courses-Of-Action, depending on the context.

When planning within a complex endeavor the effect a particular action will have must encompass multiple layers from the target, the surrounding area all the way up to national policy. In today's environment, the effects on national policy, say from collateral damage, far outweigh the military significance of a particular target.

Given this discussion, exactly what is meant by 2nd or 3rd order-effects given a particular COA? There is no clear understanding in today's environment, i.e., there is no agreed-to taxonomy that attempts to categorize what is a 2nd Order-Effect, or a 3rd Order-Effect, or even an Nth Order-Effect is for a particular COA. This paper provides a suggestive taxonomy starting with a 0ith order-effect up to a 9th Order-Effect.

Proposed Nth Order Taxonomy

In October 2002, the DoD's Command and Control Research Program developed the "Code of Best Practice for C2 Assessment (COBP)[4] where it was understood that, because of the complexity of C2 processes and systems, analysis in this area requires the ability to understand how Dimensional Parameters (DP), Measures of Performance (MoP), Measures of C2 Effectiveness (MoCE), Measures of Force Effectiveness (MoFE), and Measures of Policy Effectiveness (MoPE) are linked and impact on one another. The cumulative set of these measures is denoted as Measures of Merit (MoM) in the COBP. Determining the precise nature of these relationships nearly always proves to be an analytic challenge (NATO COBP, 2002: 5). Appendix B provides an overview of the metric structure developed in the NATO COBP study.

A key take-away from the study was that, within net-centric operations one has to consider a hierarchy of effects within any planning environment and these effects need to consider operations within a complex endeavor (Alberts, 2007: 122). A major reason for this is that a single measure does not provide enough detail to analyze the impact of specific elements (e.g., C2 system), particularly with respect to second and third order effects or unintended consequences. Unfortunately, the "NATO COBP for C2 Assessments" did not define what was meant by 2nd or 3rd order effects. (NATO COBP, 2002: 94)
Taking the work accomplished in the NATO COBP, one can represent Nth order-effects in a hierarchical form starting from the component level up to the national level. Table 1 provides that relationship as a proposed taxonomy.

[4] Document stemmed from a NATO RTO sponsored Research Group (SAS-026) and was published under the Command and Control Research Program in 2002.

Table 1: Nth Order Taxonomy Relationships

Nth Order	Description	Level	Area	MOPs/MOEs
0	Actual Event	Tactical	Local	
1	Desired Effect	Tactical	Local	DP
2	Collateral Damage (Physical)	Tactical	Local	DP
3	Collateral Damage (Non-Physical)	Tactical	Local	DP
4	C2 Systems Effectiveness	Operational	Regional	MoCE
5	Command Intent Effectiveness (e.g., JFACC, JFLCC, JFMCC)	Operational	Regional	MoFE
6	Command Intent (JTF) Effectiveness	Operational	Regional	MoFE
7	National ROE/Policy Effectiveness	Strategic	Global	MoPE
8	Coalition ROE/Policy Effectiveness	Strategic	Global	MoPE
9	International ROE/Policy Effectiveness	Strategic	Global	MoPE

From Table 1, there are three groupings within the proposed taxonomy. The first group would be the "tactical level effects." This would encompass the local area around the particular target. The second level would be the "operational level effects." This would be analogous to the region (e.g., the Area of Responsibility—AOR or a nation-state) surrounding the particular target. The third and last group would be the "strategic level effects." This would encompass the global nature of the effects around the particular target[5]. This is primarily the "policy domain" that would take into account effects on national, coalition, and international policy given a particular COA.

For each of the "layers" of effectiveness, there needs to be a methodology for the metrics that can be used to "assess" and "plan" when considering the "desired effects" for mission success within a complex endeavor. A representative sample of net-centric factors/criteria metrics that would be applicable can be found in the AF FY12 Command and Control Capabilities Analysis Team Final Report (a comprehensive list can be found in Appendix C.) (AF FY12 CAT, 2007: Appendix B)

[5] Of note here is that effects within the cyber domain can achieve "global effects" far faster than other domains due to its unique "borderless" nature. For example, a hacker in Country A can significantly impact the networks in Country B; without ever leaving Country A.

0^{th} Order Effect (Actual Event): This is the actual "touching" of the target. The methods are different depending on the domain (air, space, cyber) being utilized. This occurs primarily in the physical domain.
1^{st} Order Effect (Desired Effect): Typically this can be characterized as "D5 Effects."[6] This can occur within the physical, cognitive, information and social domains.

2^{nd} Order Effect (Collateral Damage—Physical): Typically hardware in nature (bridges, roads). Represent items that are affected that were not supposed to be. Can also be non-combatants who were injured in the event. This occurs within the physical domain.

3^{rd} Order Effect (Collateral Damage—Non-Physical): Can be software in nature but can also be in the "Court of Public Opinion". This occurs within the cognitive, social and information domains.

4^{th} Order Effect (C2 Systems Effectiveness): Covers how well and to what quality were the COAs developed, selected and executed towards stated goals and Command Intent. This would be the effectiveness of an AOC as a whole as well as the effectiveness of the sub-C2 systems contained within an AOC. This occurs within the cognitive, social, information as well as physical domains.

5^{th} Order Effect (JFACC Command Intent Effectiveness): This would be a set of measures as to how well the JFACC, JFLCC, JFMCC, etc (and associated staff) developed "Command Intent."[7] At this level of C2, items such as situational awareness, situational understanding, and speed of command become important metrics that can be applied. This occurs within cognitive, social as well as the information domain.

6^{th} order Effect (JTF Command Intent Effectiveness): This would be a set of measures as to how well the JFC (and associated staff) developed "Command Intent." At this level of C2, items such as joint situational awareness, joint situational understanding, and speed of command become important metrics that can be applied. This occurs within cognitive, social as well as the information domain.

7^{th} Order Effect (National ROE/Policy Effectiveness): This would be a set of measures as to how well, at the National Level, the military/political leaders (and associated staff) developed what could be termed "National Command Intent." At this level of C2, items such as Rules of Engagement and Policy Statements become important metrics that can be applied. This occurs within cognitive, social as well as the information domain.

[6] D5 = Deny, Deceive, Destroy, Disrupt, and Degrade.
[7] Initially this was termed "Commander's Intent", but as the concept of Net-centricity has evolved a more appropriate term is "Command Intent."

8th Order Effect (Coalition ROE/Policy Effectiveness): This would be a set of measures as to how well, at the Coalition Level, the military/political leaders (and associated staff) developed what could be termed "Coalition Command Intent." At this level of C2, items such as Rules of Engagement and Policy Statements become important metrics that can be applied. This occurs within cognitive, social as well as the information domain.

9th Order Effect (International ROE/Policy Effectiveness): This would be a set of measures as to how well, at the international Level, the military/political leaders (and associated staff) developed what could be termed "International Command Intent." At this level of C2, items such as Rules of Engagement and Policy Statements become important metrics that can be applied. This occurs within cognitive, social as well as the information domain.

Nth-Order Taxonomy Examples

There are two major principles that are used when discussing elements of national power, namely DIME (Diplomatic, Information, Military, and Economic) and PEMSII (Political, Economic, Military, Social, Infrastructure, and Information). The sum of these two areas can be used as descriptors to attempt to measure (either quantitatively or qualitatively) the effect, given a set of potential courses-of-action (COA). To describe a Nth order-effects taxonomy, a combination of the two principles was used to provide a basic seven item system of descriptors for the 0th to 9th order-effects, namely political, diplomatic, social, economic, military, information, and infrastructure. Table 2 provides some top-level examples regarding each of the Nth-orders.

Table 2: Nth-Order Taxonomy Examples

Order	Title	Political	Diplomatic	Social	Economic	Military	Information	Infrastructure
0	Actual Event	Nation-state to Nation-state	Impose "Sanctions"	Impose "Beliefs"	""Freezing" Assets	Destroy, Degrade, Deceive, Deny, Disrupt a Military Target	Destroy, Degrade, Deceive, Deny, Disrupt an Information Target	Destroy, Degrade, Deceive, Deny, Disrupt an Infrastructure Target
1	Desired Effect	Favorable outcome	Favorable outcome	Favorable outcome	Favorable outcome	Favorable outcome	Favorable outcome	Favorable outcome
2	Collateral Damage - Physical	Expelling of US Ambassador or member of embassy staff	Expelling of US Ambassador or member of embassy staff	Desired "beliefs" spilling over into other undesired areas	Others effected with "Freezing Assets" that was unintentional	Destroy, Degrade, Deceive, Deny, Disrupt a Target unintentionally	Destroy, Degrade, Deceive, Deny, Disrupt a Target unintentionally	Destroy, Degrade, Deceive, Deny, Disrupt a Target unintentionally
3	Collateral Damage – Non-Physical	Seeking "World Opinion" that is contrary to desired effects	Retaliation in another area.	Desired "beliefs" spilling over into other undesired areas	Others effected with "Freezing Assets" that was unintentional (e.g., emotional stress)	Destroy, Degrade, Deceive, Deny, Disrupt a Target unintentionally	Destroy, Degrade, Deceive, Deny, Disrupt a Target unintentionally	Destroy, Degrade, Deceive, Deny, Disrupt a Target unintentionally
4	C2 Systems Effectiveness	System does not provide nor incorporate robust set of political options in a timely manner.	System does not provide nor incorporate robust set of diplomatic options in a timely manner.	Fully comprehensive COA that takes into account DIME and PEMSII effects	Fully comprehensiv e COA that takes into account DIME and PEMSII effects	Fully comprehensive COA that takes into account DIME and PEMSII effects	Full set of capabilities that provide quality action-oriented information	Provides timely information when and where needed
5	Command Intent (JFACC) Effectiveness	JFACC does not provide nor incorporate robust set of options in a timely manner.	JFACC does not provide nor incorporate robust set of options in a timely manner.	JFACC does not provide nor incorporate robust set of options in a timely manner.	JFACC does not provide nor incorporate robust set of options in a timely manner.	JFACC does not provide nor incorporate robust set of options in a timely manner.	JFACC does not provide nor incorporate robust set of options in a timely manner.	JFACC does not provide nor incorporate robust set of options in a timely manner.
6	Command Intent (JFC) Effectiveness	JFC does not provide nor incorporate robust set of political options in a timely manner.	JFC does not provide nor incorporate robust set of diplomatic options in a timely manner.	JFC does not provide nor incorporate robust set of social options in a timely manner.	JFC does not provide nor incorporate robust set of economic options in a timely manner.	JFC does not provide nor incorporate robust set of military options in a timely manner.	JFC does not fully utilize the capabilities of the information provided to develop a robust set of options in a timely manner.	JFC does not fully utilize the capabilities of the available infrastructure provided to develop a robust set of options in a timely manner.
7	National ROE/Policy Effectiveness	The National level does not provide nor incorporate robust set of political options or ROEs in a timely manner.	The National level does not provide nor incorporate robust set of diplomatic options or ROEs in a timely manner.	The National level does not provide nor incorporate robust set of social options or ROEs in a timely manner.	The National level does not provide nor incorporate robust set of economic Options or ROEs in a timely manner.	The National level does not provide nor incorporate robust set of military options or ROEs in a timely manner.	The National level does not fully utilize the capabilities of the information provided to develop a robust set of options or ROEs in a timely manner.	The National level does not fully utilize the capabilities of the available infrastructure provided to develop a robust set of options or ROEs in a timely manner.
8	Coalition ROE/Policy Effectiveness	The Coalition level does not provide nor incorporate robust set of political options or ROEs in a timely manner.	The Coalition level does not provide nor incorporate robust set of diplomatic options or ROEs in a timely manner.	The Coalition level does not provide nor incorporate robust set of social options or ROEs in a timely manner.	The Coalition level does not provide nor incorporate robust set of economic Options or ROEs in a timely manner.	The Coalition level does not provide nor incorporate robust set of military options or ROEs in a timely manner.	The Coalition level does not fully utilize the capabilities of the information provided to develop a robust set of options or ROEs in a timely manner.	The Coalition level does not fully utilize the capabilities of the available infrastructure provided to develop a robust set of options or ROEs in a timely manner.
9	International ROE/Policy Effectiveness	The International level does not provide nor incorporate robust set of political options or ROEs in a timely manner.	The International level does not provide nor incorporate robust set of diplomatic options or ROEs in a timely manner.	The International level does not provide nor incorporate robust set of social options or ROEs in a timely manner.	The International level does not provide nor incorporate robust set of economic Options or ROEs in a timely manner.	The International level does not provide nor incorporate robust set of military options or ROEs in a timely manner.	The International level does not fully utilize the capabilities of the information provided to develop a robust set of options or ROEs in a timely manner.	The International level does not fully utilize the capabilities of the available infrastructure provided to develop a robust set of options or ROEs in a timely manner.

Mathematical Representations of Nth-Order Effects

Given the proposed nth order-effects taxonomy, there are numerous methods of performing analysis to determine "effects" on "mission effectiveness" within a complex endeavor. Since performing analysis on nth order-effects is primarily qualitative (e.g., using a four-part evaluation: totally-unacceptable, unacceptable, acceptable, totally acceptable), using "subjective logic" (See Appendix D for a short overview) is a possibility. The mathematical representation can be shown as:

MOE(nth Order) = f(belief) + f(disbelief) + f(uncertainty)

This would entail using disbelief uncertainty algebra for nth order analysis. (Denny, 2010: Paper 113) Denny's paper describes a methodology that can translate a particular nth order effect into a Measure of Effectiveness (MOE). The scale could be a continuous range from 0 to 1 for each of the variables [belief (b), disbelief (d) and uncertainty (u)]. The resultant nth order effect measure:

0 = Detrimental to Operations,

.25 = Unacceptable,

.50 = Acceptable,

.75 = Very Acceptable,

1 = Significantly Acceptable to Operations

A way of graphically displaying the results could be by spider graph. Figure 4 illustrates an example for comparing two different Courses-of-Action (COA) options for a particular nth order-effect (e.g., 5th Order-Effect: Command Intent (JFACC) Effectiveness). As shown, COA-B option provides significantly better effectiveness for the sub-items under the 5th Order-Effect: Command Intent (JFACC) Effectiveness.

However, to determine overall mission effectiveness, for example at the campaign level (JTF), a cross order-effects analysis needs to be performed. This would provide an analysis illustrating the inter-relationships of the effects from the 0th to 9th order. For each of the nth order-effects, a watermelon chart could be used to collectively show how the effects impact the operational mission being formed as a complex endeavor. For example, if an analysis is being performed on the 5th order (Effectiveness of Command Intent of the JFACC), Figure 5 illustrates the resultant analysis where: C1=Infrastructure, C2=Information, C3=Political, C4=Diplomatic, C5=Social, C6=Economic, and C7=Military. As shown, weak effectiveness of the Military (C7) will have a

catastrophic effect on mission while robust effectiveness of Economics (C6) will have a negligible impact on mission accomplishment.

Figure 4: Spider Graph Representation of Effectiveness[8]

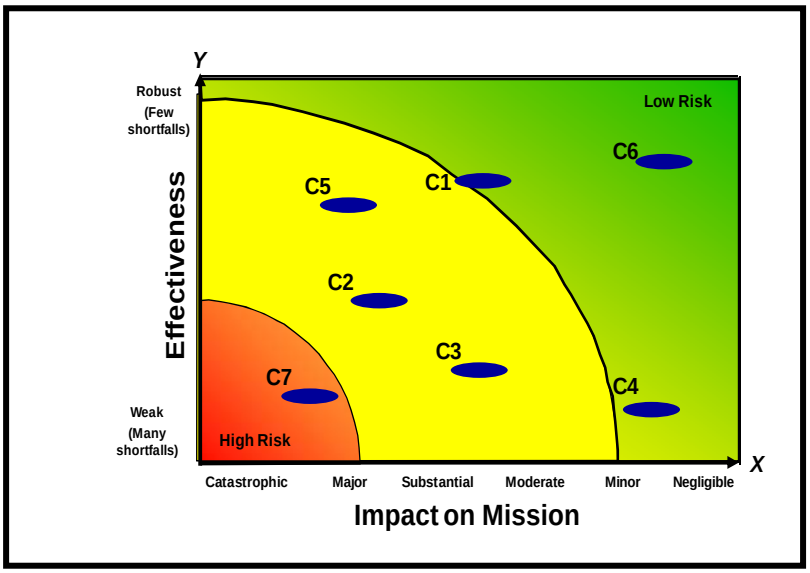

Figure 5: Watermelon Representation of Impact on Mission[9]

[8] Data does not represent actual values. They are included for illustrated purposes only.
[9] Data does not represent actual values. They are included for illustrated purposes only.

Figure 6: Campaign Level Representation of Mission Effectiveness[10]

Figures 4, 5 and 6 are just samples of the types of analytical representations that can be formed to illustrate the effects for each of the nth orders into a single, integrated representation. The key is to incorporate all nine layers of the taxonomy during the planning and assessment phases of any operation. This is a more robust incorporation of effects-based operations to provide a more comprehensive view of potential effects given a set of COA.

[10] Data does not represent actual values. They are included for illustrated purposes only.

Conclusions

Within a net-centric operations environment, military commanders need to plan/assess operations within a "complex endeavor" context. Potential COAs must incorporate impacts from areas like: political, diplomatic, social and economic as well as traditional military, information and infrastructure (i.e., DIME and PEMSII).

A suggested methodology is a $0^{th} – 9^{th}$ order-effects taxonomy to give a more robust, complete and consistent analysis of potential COAs.

Since the resultant analysis is more qualitative than quantitative, a "subjective logic" analytical approach is suggested. This approach takes into account qualitative variables, such as belief, disbelief, and uncertainty when applied to the various order-effects list. Consequently, a more robust analysis can be performed on potential COAs.

The goal is to select better, more comprehensive COAs that minimize the unacceptable aspects and maximize the effectiveness of mission operations within a complex endeavor.

Glossary

Cyberspace	A global domain within the information environment consisting of the interdependent network of information technology infrastructures, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers. DoD Joint Pub 1-02, page 86
Global Vigilance	Ability to keep an unblinking eye on any entity - to provide warning on capabilities and intentions, as well as identify needs and opportunities. CSAF's Vector, 2008
Global Reach	Ability to move, supply or position assets – with unrivaled velocity and precision anywhere. CSAF's Vector, 2008
Global Power	Ability to hold at risk or strike any target, anywhere, and project swift, frequently decisive, precise effects. CSAF's Vector, 2008

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Appendix A: Operational Timelines and Relationships

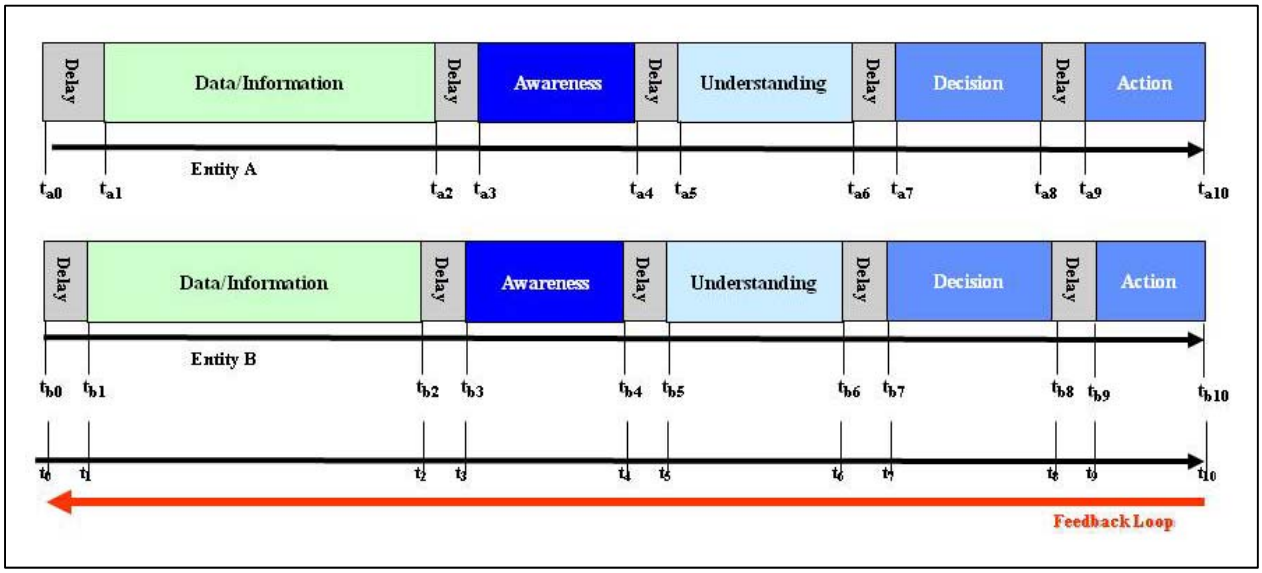

Figure A-1: Timeline From Data/Information (t_0) to Action (t_{10})

Timeline	Relationship
Definitions	
t0	Start of particular time reference
t8	Time collaborative decision is made
ta8	Time entity A decision is made
tb8	Time entity B decision is made
ta10	Time to Action for entity A
tb10	Time to Action for entity B
ta3-ta0 or tb3-tb0	Currency of the data/information
MAX(ta3,tb3) – t0	Currency of the Shared Information
MAX(ta5,tb5) – t0	Currency of Shared Awareness
MAX(ta7,tb7) – t0	Currency of Shared Understanding
MAX(ta9,tb9) – t0	Currency of Shared Decisions
MAX(ta10,tb10) – t0	Currency of Shared Actions
Basic Times	
ta2 – ta0, tb2 – tb0	Time to receive, process, disseminate data/information
ta4 – ta2, tb4 – tb2	Time to analyze and gain Awareness
ta6 – ta4, tb6 – tb4	Time to analyze and gain Understanding
ta8 – ta6, tb8 – tb6	Time to analyze and make a decision (Speed of Decision)
Individual Times	
ta4 – ta0, tb4 – tb0,	Time to Awareness
ta6 – ta0, tb6 – tb0,	Time to Understanding
ta8 – ta0, tb8 – tb0,	Time to make a Decision (Speed of Command)
ta10 – ta0, tb10 – tb0	Time to Action (Speed of Action)
Collaboration Times	
MAX(ta4,tb4) – t0	Time to Shared Awareness (time to achieve a Collective Awareness)
MAX(ta6,tb6) – t0	Time to Shared Understanding (time to achieve a Collective Understanding)
MAX(ta8,tb8) – t0	Time to make a Shared Decision (Joint Speed of Decision)
MAX(ta10,tb10) – t0	Time to Shared Action (Joint Speed of Action)

Table A-1: Net-Centric Operations Timeline and Relationships

Appendix B: Net-Centric Operations Levels of Metrics

A key aspect of the work performed under the NATO COBP endeavor was the consideration of a hierarchy when dealing with effectiveness in a net-centric environment. The important issues addressed in the COBP were to which C2 performance may improve force and policy effectiveness.
Figure B-1 provides a hierarchical view. The column on the left indicates the level and the column on the right provides an example.

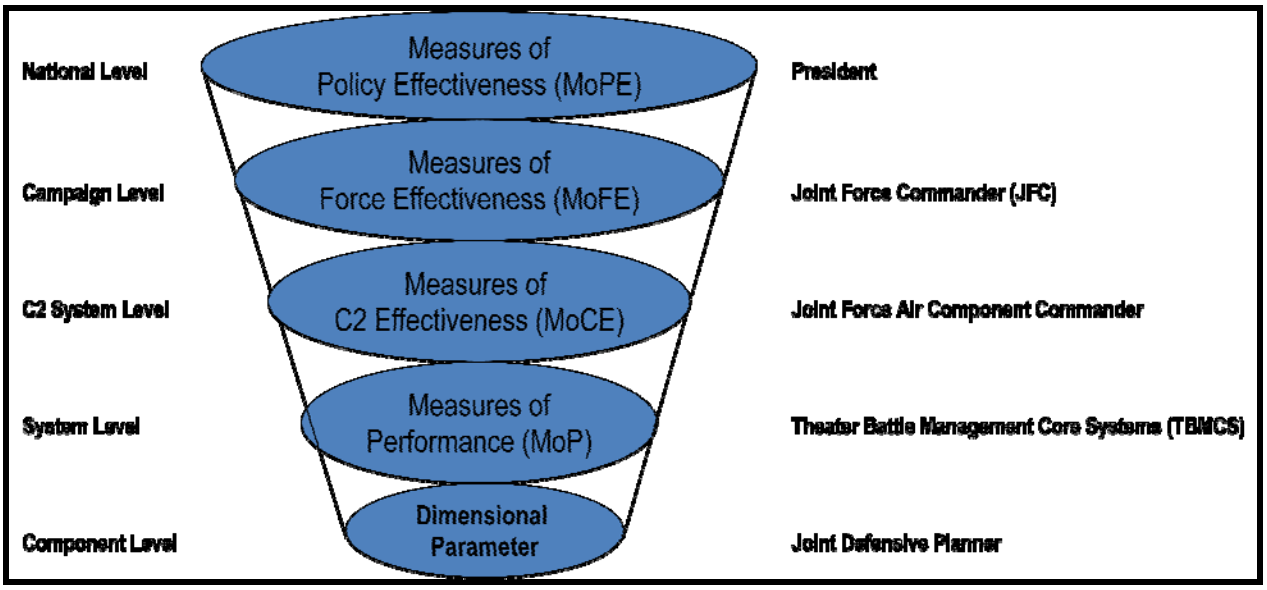

Figure B-1: Hierarchical View of Measures of Effectiveness (NATO COBP, 2002: 92)

Where:
MoM = Set of variables that focus the assessment on the issues of interest.
MoPE = focus on policy and societal outcomes
MoFE = focus on how a force performs its mission or the degree to which it meets its objectives
MoCE = focus on the impact of C2 systems within the operational context
MoP = focus on internal system structure, characteristics and behavior
DP = focus on the properties or characteristics inherent in the physical C3 systems

Appendix C: Net-Centric Factors/Criteria Metrics

The metrics below is a combination of net-centric metrics that have been used to date[11].

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Accessibility: data/information	Percent of time users are provided with (or retrieve from) needed products under various loading conditions.
Accessibility: network	Percent of time a network is available for use by users to provide needed products under various loading conditions.
Accountability: individual decisions	Measures the degree to which individual decisions are "accountable" given the situation. Metric is an accountability scale in percent (0%=not accountable of individual decisions needed and what is available, 100%=max accountability between individual decisions needed and available.
Accountability: collaborative decisions	Measures the degree to which collaborative decisions are "accountable" given the situation. Metric is an accountability scale in percent (0%=not accountable of collaborative decisions needed and what is available, 100%=max accountability between collaborative decisions needed and available.
Accuracy: data/information	Measure of error. Metric is a percent scale (0%=no match between precision level needed and what is available, 100%=high degree of matching between precision level needed and available. Examples: avg miss distance: +/-x feet; MHz: +/- x hertz
Accuracy: shared data/information	Measure of error regarding shared information between entities. Metric is a percentage scale (0%=no match between shared data/information needed and what is available, 100%=high degree of matching between shared information needed and available.
Accuracy: shared awareness	Measure of error regarding shared awareness between entities. Metric is a percentage scale (0%=no match between shared awareness needed and what is available, 100%=high degree of matching between shared awareness needed and available.
Accuracy: shared understanding	Measure of error regarding shared understanding between entities. Metric is an ordinal scale (0=no match between shared understanding needed and what is available, 10=high degree of matching between shared understanding needed and available.
Availability: data/information	Percent of time users are provided with needed products under various loading conditions. Squadron, wing, base, NAF, MAJCOM, Air Force level, Joint level
Availability: shared awareness	Percent of time individuals "share" awareness.
Availability: individual decisions	Percent of time individuals "share" decisions.
Availability: collaborative decisions	Percent of time individuals "share" collaborative decisions.
Availability: individual understanding	Percent of time individuals "share" understanding.
Availability: shared understanding	Percent of time individuals "share" understanding
Awareness	Awareness is a process state existing in the cognitive domain. It takes place in the minds of key leaders and their supporting battlestaffs, not in computers. Awareness is achieved through a complex interaction of available information (e.g., COP) with prior knowledge and beliefs representing the experience and expertise of the battlestaff. Awareness relates to the operational situation as it currently is or was in the past. Human perception of the situation as it is and as it is becoming.
Collective Awareness	Collective awareness is the sum of the elements of situational awareness held by all the actors within a military, interagency, or coalition structure.

[11] For example, the AF FY12 C2 Capabilities Analysis Team's Final Report lists these unclassified metrics in their Appendix B. These metrics are from open sources and is public releasable.

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Collective Knowledge	Degree to which team members have the knowledge, skills, attributes, and abilities that they need to accomplish the task at hand
Combat Assessment	Battle Damage Assessment (BDA) + Munitions Effectiveness Assessment (MEA), a subset of which is Bomb Impact Assessment (BIA) + Mission Assessment (MA); Re-attack recommendation.
Completeness: data/information	Measures the completeness of the data/information provided. Metric is the percentage of relevant data/information received to a ground truth containing all the data/information
Completeness: shared data/information	Measures the completeness of the data/information shared between entities. Metric is the percentage of relevant shared data/information received to a ground truth containing all the data/information
Completeness: shared awareness	Measures the shared awareness between entities. Metric is the percentage of relevant shared awareness received to a ground truth containing all the data/information
Completeness: shared understanding	Measures the shared understanding between entities. Metric is the percentage of relevant shared understanding received to a ground truth containing all the data/information
Computer Intrusion Detection	Denial of service; scanning and probing; password attacks; privilege grabbing; hostile code insertion; cyber vandalism; proprietary data theft; fraud, waste and abuse; audit trail tampering; security admin attacks.
Consistency: data/information	Measures the degree of "deviation" from previous data/information gained from previous time period. Measure is a percentage deviation.
Consistency: shared data/information	Measures the degree of "deviation" from previous data/information shared gained from previous time period. Measure is a percentage deviation.
Consistency: shared awareness	Measures the degree of "deviation" from shared awareness gained from previous time period. Measure is a percentage deviation.
Consistency: shared understanding	Measures the degree of "deviation" from shared understanding gained from previous time period. Measure is a percentage deviation.
Correctness: Organic Information	Measure to determine the correctness of organic information. Metric is a convergence index (0=no correspondence with ground truth, 1=full correspondence with ground truth) Data matrix comprised of relevant information items estimates (for instance: detection, ID, velocity, location, heading, etc.)
Correctness: Shared Information	Measures the correctness of the data/information that is shared between two entities. Metric is a convergence index (0=no convergence, 1=full convergence) between shared information and ground truth
Correctness: Shared Awareness	Measures the level of shared awareness between two entities. Metric is a convergence index (0=no awareness, 1=full awareness) between shared awareness and ground truth
Correctness: Shared understanding	Measures the level of shared understanding between two entities. Metric is a convergence index (0=no awareness, 1=full awareness) between shared understanding and ground truth
Currency: data/information	Measures the age of the data/information from the time it was originally created
Currency: shared data/information	Measures the age (time lag) of the shared data/information from the time it was originally shared between entities
Currency: shared awareness	Measures the age (time lag) of the shared awareness from the time it was originally shared between entities
Currency: shared understanding	Measures the age (time lag) of the shared understanding from the time it was originally shared between entities
Decision Maker: Leadership	Measures the ability of the decision maker to motivate and inspire individuals and build teams to achieve mission objectives. Metric is a five level scale (VL, L, M, H, and VH) of a decision maker's leadership capability.
Decision Maker: Confidence	Measures the ability of the decision maker to gain the trust of superiors, peers, and subordinates by demonstrating integrity, professional competence, and dedication to successfully completing the current mission. Metric is a five level scale (VL, L, M, H, and VH) of a decision maker's confidence factor.

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Decision Maker: Balance	Measures the ability of the decision maker to balance personal health and mental well being with the demands of the job in order to stay fresh, alert, and effective. Metric is a five level scale (VL, L, M, H, and VH) of a decision maker's ability to balance numerous factors in order to conduct mission operations.
Decision Maker: Decisiveness	Measures the ability of the decision maker to provide decisive decisions in the conduct of military operations. Metric is a continuous level scale (0%=not decisive 50%=somewhat decisive, 100%=extremely decisive).
Decision Maker: Adaptability	Measures the ability of the decision maker to adaptive to withstand or adjust to changes in the battlespace. Metric is a continuous level scale (0%=not adaptable 50%=somewhat adaptable, 100%=extremely adaptable).
Decision Maker: Interpersonal Communications Skills	Measures the interpersonal communications skills of the decision maker. Metric is a continuous level scale (0%=little to no interpersonal communications skills, 50%=medium interpersonal communications skills, 100%=high degree of interpersonal communications skills).
Decision Maker: Projection	Measures the ability of a decision maker to conceptualize future actions and events based on relevant factors. Metric is a continuous level scale (0%=little to no ability to project, 50%=medium projection skills, 100%=high degree of projection skills).
Decision Maker: Multi-Tasking Ability	Measures the ability of the decision maker to multi-task to effectively manage time and priorities to accomplish multiple activities simultaneously within the battlespace. Metric is a continuous level scale (0%=does not have any multi-tasking abilities, 50%=demonstrates some multi-tasking abilities, 100%=exhibits extreme multi-tasking abilities).
Decision Maker: Concentration	Measures the ability of a decision maker to maintain focus and deal with uncertainty through the "fog of war". Metric is a continuous level scale (0%=little concentration ability, 50%=medium concentration ability, 100%=high degree of concentration ability).
Decision Maker: Negotiation Ability	Measures the ability of the decision maker to tactfully resolve difficult situations when internal and external partners disagree due to contrasting opinions, goals, priorities, methods, and /or solutions. Metric is a five level scale (VL, L, M, H, and VH) of the decision maker's negotiation ability or skill.
Decision Maker: Courage	Measures the decision maker's ability to do the right thing at the right time in spite of pressure to do otherwise. Includes the ability to talk about doubt, uncertainty, and bad news. Metric is a continuous level scale (0%=exhibits little to no courage, 50%=exhibits sufficient courage, 100%=demonstrates extreme courage).
Decision Maker: Objectivity	Measures the ability of the decision maker to clearly look at the operational situations (Blue, Red, Gray, and White) as they unfold within the battlespace. Metric is a continuous level scale (0%=exhibits little to no objectivity, 50%=exhibits sufficient objectivity, 100%=demonstrates extreme objectivity).
Decisions: Collaborative Accuracy	Measures the degree to which collaborative decisions are "accurate" given the situation. Metric is a percentage scale (0%=no match between collaborative decisions needed and what is available, 100%=high degree of matching between collaborative decisions needed and available.
Decisions: Collaborative Adaptability	Measures the ability of a decision maker to alter collaborative decisions when necessary as the situation changes. Metric is a percentage scale (0%=cannot adapt, 50%= show some adaptability, 100%=shows significant adaptability)
Decisions: Collaborative Appropriateness	Measures the degree to which collaborative decisions are appropriate given the situation. Metric is a percentage scale (0%=collaborative decision not appropriate to situation, 50%=collaborative decision may or may not be appropriate to situation, 100%=high degree of appropriateness between collaborative decisions needed and available)
Decisions: Collaborative Consistency	Measures the degree of collaborative decision "consistency". Metric is a percentage index that relates the degree of "deviation" from previous collaborative decisions (0%= no consistency, 50%=some consistency, 100%=maximum consistency)
Decisions: Collaborative Completeness	Measures the degree of decision "completeness". Metric is the percentage of individual decision relevant to the situation at hand (0%=no relevance, 50%=somewhat relevant, 100%=maximum relevancy)
Decisions: Collaborative Currency	Measures the time to make a collaborative decision. Metric is an index that measures the time it takes a decision maker to make a collaborative decision given a situation.
Decisions: Collaborative Flexibility	Measures the ability of a decision maker to make collaborative decisions in different situations. Metric is a percentage flexibility scale (0%=not flexible, 50%=some flexibility, 100%=significant flexibility)
Decisions: Collaborative Innovation	Measures the ability of a decision maker to make collaborative decisions in new ways or to understand new things. Metric is a percentage scale (0%=shows no innovation, 50%=shows some innovation, 100%=shows significant innovation)

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Decisions: Collaborative Mode of Decision Making	Measures the controlling nature of the decision maker in a collaborative situation. Metric is a percentage scale (0%=no control, 50%=some control, 100%=total control).
Decisions: Collaborative Precision	Measures the level of detail of a particular collaborative decision given a situation. Metric is a percentage scale (0%=no detail, 50%=some details, 100%=significant detail)
Decisions: Collaborative Relevance	Measures the degree to which collaborative decisions are "relevant" given the situation. Metric is a percentage collaborative relevance scale (0%=collaborative decisions not relevant, 50%=collaborate decisions somewhat relevant, 100%=high degree of relevancy between collaborative decisions needed and available.
Decisions: Collaborative Responsiveness	Measures the ability of a decision maker to make effective collaborative decisions given a situation. Metric is a percentage scale (0%=does not make effective collaborative decisions, 50%=makes some effective collaborative decisions, 100%=makes significant effective collaborative decisions)
Decisions: Collaborative Risk Propensity	Measures the decisions makers "collaborative risk taking" ability given a situation. Metric is a percentage risk level (0%=minimal risk, 100%=maximum risk) or risk interval (95%, 90%) of collaborative decisions
Decisions: Collaborative Robustness	Measures the ability of a decision maker to use levels of collaborative decisions across a range of missions that span the spectrum of conflict. Metric is a percentage scale (0%=no robustness, 50%=some robustness, 100%=significant robustness)
Decisions: Collaborative Timeliness	Measures the timeliness to which a decision maker makes "collaborative decisions" given a situation. Metric is a percentage scale (0%=does not make collaborative decisions in time to influence an outcome of a given situation, 100%=always makes collaborative decisions in time to influence an outcome to a given situation)
Decisions: Collaborative Uncertainty	Measures the uncertainty level of a collaborative decision given a situation. Metric is a percentage confidence scale (0%=uncertain, 100%=certain) or confidence interval (95%, 90%) of collaborative decisions.
Decisions: Individual Accuracy	Measures the degree to which decisions are "accurate" given the situation. Metric is a percentage accuracy scale (0%=no match between individual decisions needed and what is available, 50%=medium match between individual decisions needed and what is available, 100%=high degree of matching between individual decisions needed and available.
Decisions: Individual Adaptability	Measures the ability of a decision maker to alter individual decisions when necessary as the situation changes. Metric is a percentage scale (0%=cannot adapt, 50%= show some adaptability, 100%=shows significant adaptability)
Decisions: Individual Appropriateness	Measures the degree to which decisions are appropriate given the situation. Metric is a appropriate scale in percentages (0%=individual decision not appropriate to situation, 100%=high degree of appropriateness between individual decisions needed and available)
Decisions: Individual Consistency	Measures the degree of decision "consistency". Metric is a percentage index that relates the degree of "deviation" from previous decisions (0%=no deviation, 50%=some deviation, 100%=max deviation).
Decisions: Individual Completeness	Measures the degree of decision "completeness". Metric is the percentage of individual decision relevant to the situation at hand
Decisions: Individual Currency	Measures the time to make a decision. Metric is an index that measures the time it takes a decision maker to make a decision given a situation
Decisions: Individual Flexibility	Measures the ability of a decision maker to make individual decisions in different situations. Metric is a percentage flexibility scale (0%=not flexible, 50%=some flexibility, 100%=significant flexibility)
Decisions: Individual Innovation	Measures the ability of a decision maker to make individual decisions in new ways or to understand new things. Metric is a percentage scale (0%=shows no innovation, 50%=shows some innovation, 100%=shows significant innovation)
Decisions: Individual Mode of Decision Making	Measures the controlling nature of the decision maker. Metric is a percentage scale (0%=no control, 50%=some control, 100%=total control).
Decisions:	Measures the level of detail of a particular decision given a situation. Metric is a percentage scale (0%=no detail, 50%=some

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Individual Precision	details, 100%=significant detail)
Decisions: Individual Relevance	Measures the degree to which decisions are "relevant" given the situation. Metric is a percentage scale (0%=individual decisions not relevant, 100%=high degree of relevancy between individual decisions needed and available.
Decisions: Individual Responsiveness	Measures the ability of a decision maker to make effective individual decisions given a situation. Metric is a percentage scale (0%=does not make effective decisions, 50%=makes some effective decisions, 100%=makes significant effective decisions)
Decisions: Individual Risk Propensity	Measures the decisions makers "risk taking" ability given a situation. Metric is a percentage scale measuring the risk level (0%=minimal risk, 100%=maximum risk) or risk interval (95%, 90%) of individual decisions
Decisions: Individual Robustness	Measures the ability of a decision maker to use levels of decisions across a range of mission that span the spectrum of conflict. Metric is a percentage scale (0%=no robustness, 50%=some robustness, 100%=significant robustness)
Decisions: Individual Timeliness	Measures the timeliness to which a decision maker makes "decisions" given a situation. Metric is a percentage timeliness scale (0%=does not make decisions in time to influence an outcome of a given situation, 50%=makes decisions most of the time to influence an outcome of a given situation, 100%=always makes decisions in time to influence an outcome to a given situation)
Decisions: Individual Uncertainty	Measures the uncertainty level of a decision given a situation. Metric is a percentage that measures confidence scale (0%=uncertain, 100%=certain) or confidence interval (95%, 90%) of individual decisions.
Effectiveness: Achievement of Objectives	Measures the degree to which mission objectives are achieved. Metric is an ordinal scale (0%=no achievement, 100%=maximum achievement) or achievement interval (95%, 90%) of mission objectives.
Effectiveness: Agility	Measures the ability to modify forces objectives in a timely manner. Metric is an ordinal scale (0=not agile, 100=maximum agility)
Effectiveness: Mission	Measures the degree to which a force accomplishes its assigned military mission. It is multi-attributed. These metrics exist largely at the operational level and below when thinking inside the context of "traditional" military missions. Metric is percentage of mission effectiveness.
Effectiveness: Timeliness	Measures the ability to achieve a mission objective in a timely manner. Metric is achieved mission objectives divided by total mission objectives over a given time interval.
Effectiveness: Efficiency	Measures the ability to achieve a mission objective in an efficient manner. Metric is an ordinal scale (0=not efficient, 100=maximum efficiency)
Extent: degree of data/information	Measures the extent of shared data/information
Extent: degree of Shared Awareness	Measures the extent of shared awareness
Interaction: Individual Adaptability	Measures the ability to alter interactions when necessary as the situation changes. Metric is a percentage scale (0%=no adaptability, 50%=some adaptability, 100%=significant adaptability)
Interaction: Individual Confidence	Measures the state of being certain. Metric is a percentage index of confidence in the individual ranging from 0%=no confidence to 100%=total confidence.
Interaction: Individual Latency	Measures the time lag to conduct interactions from the start of a particular situation. Metric is a time interval that measures the time lag.
Interaction: Individual Quality	Measures the quality of the interactions present during a particular situation. Metric is a percentage scale (0%=poor quality, 50%=medium quality, 100%=high quality)
Interaction: Individual Quantity	Measures the quantity of interactions present during a particular situation. Metric is a percentage scale that measures the quantity of interactions per interval of time.
Interaction: Individual Reach	Measures the end-to-end distance interaction occurs. Metric are a percentage of nodes (locations) that can interact in desired access modes.
Interaction:	Measures the state of being certain. Metric is a percentage index of confidence in the organization ranging from 0%=no

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Organization Confidence	confidence to 100%=total confidence.
Inter-cooperability: Organization-to-Organization	The ability of an organization(s) to function together essentially as a single organization to essentially achieve shared understanding among each other and to use the information exchanged to interact effectively, interdependently and adaptively toward a common and valued set of goals. The metric would measure the level of inter-cooperability (0-none, 50%-average, 100%-maximum) between each of the organizations involved.
Inter-cooperability: Individual-to-Individual	The ability of individual(s) to function together essentially as a single entity to essentially achieve shared understanding among each other and to use the information exchanged to interact effectively, interdependently and adaptively toward a common and valued set of goals. The metric would measure the level of inter-cooperability (0-none, 50%-average, 100%-maximum) between each of the individual involved.
Inter-cooperability: Individual-to-team	The ability of an individual and teams to function together essentially as a single entity to essentially achieve shared understanding among each other and to use the information exchanged to interact effectively, interdependently and adaptively toward a common and valued set of goals. The metric would measure the level of inter-cooperability (0-none, 50%-average, 100%-maximum) between the individual and team.
Inter-cooperability: Individual-to-Organization	The ability of individual(s) and organizations to function together essentially as a single entity to essentially achieve shared understanding among each other and to use the information exchanged to interact effectively, interdependently and adaptively toward a common and valued set of goals. The metric would measure the level of inter-cooperability (0-none, 50%-average, 100%-maximum) between the individual and organization.
Inter-cooperability: Team-to-Organization	The ability of a team and organization to function together essentially as a single entity to essentially achieve shared understanding among each other and to use the information exchanged to interact effectively, interdependently and adaptively toward a common and valued set of goals. The metric would measure the level of inter-cooperability (0-none, 50%-average, 100%-maximum) between the team and organization.
Inter-cooperability: Team-to-Team	The ability of teams to function together essentially as a single entity to essentially achieve shared understanding among each other and to use the information exchanged to interact effectively, interdependently and adaptively toward a common and valued set of goals. The metric would measure the level of inter-cooperability (0-none, 50%-average, 100%-maximum) between teams.
Maintainability: data/information	Measures the maintainability of the data/information. Metric, depicted as a percentage, is the ease to which the data/information is maintained within the specified system (0%=not maintainable by pre-defined standards, 50%=somewhat maintainable by pre-defined standards, 100%=totally maintainable within pre-defined standards).
Maintainability: system	Measures the maintainability of a particular system. Metric, depicted as a percentage, is the ease to which the system is maintained within pre-defined standards – e.g., equipment accessibility, shop replaceable unit, line replaceable units, and depot level repair. (0%=not maintainable by pre-defined standards, 50%=somewhat maintainable by pre-defined standards, 100%=totally maintainable within pre-defined standards).
Maintainability: network	Measures the maintainability of a particular network. Metric, depicted as a percentage, is the ease to which the network is maintained within pre-defined standards – e.g., equipment accessibility, shop replaceable unit, line replaceable units, and depot level repair. (0%=not maintainable by pre-defined standards, 50%=somewhat maintainable by pre-defined standards, 100%=totally maintainable within pre-defined standards).
Network Agility	Measures the ability to modify an entire network un a timely manner. Metric is a percentage rating of agility (0% = no agility, 50% = medium agility, 100%=maximum agility)
Network Assurance	Measures the security of an entire network. Metric is a percentage rating of network security (100% = highly secure, 90% = secure, 0% = not secure) based on network and node encryption levels, type of security management systems provided, etc.
Network Availability	Measures the time all authorized users have access to the network. This is necessary if current information is to be shared and if the user community is to develop trust and confidence in using the information in the system. Metric is percentage of time network is available to users.
Network Reach	Measures the end-to-end extent (or reach) of the network. Metric is the percent of nodes that can communicate in desired access modes, information formats, and applications
Network Richness	Measures the quality and breath of the information found in the network. Metric is a percentage scale (0%=not rich, 50%= some richness, 100%=maximum richness) or interval scale (95%, 90%) of network richness.
Network Reliability	Measures the network's ability to consistently produce the same results. Metric is a percentage scale (0%=not reliable, 50%= somewhat reliable, 100%=maximum reliability) or interval scale (95%, 90%) of network reliability.
Precision: data/information	Measures the level of measurement detail of a data/information item. For example, Measure of repeatability, probability of damage/kill (Pd/Pk)
Precision: shared data/information	Measures the level of granularity of a shared data/information item. Measure is percentage deviation from actual "truth", for example Frequency +- 5%.

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Precision: shared awareness	Measures the level of granularity of shared awareness. Measure is percentage deviation from actual "truth", for example, 9/10 commanders have the same awareness equates to 90% of shared awareness.
Precision: shared understanding	Measures the level of granularity of shared understanding. Measure is percentage deviation from actual "truth", for example, 9/10 commanders have the same understanding equates to 90% of shared understanding.
Relevance: data/information	Measures the proportion of information collected that is related to the task at hand
Relevance: shared data/information	Measures the proportion of shared information collected that is related to the task at hand. Metric is a percentage scale that measures the relevance of the shared data/information (0%=no relevance, 50% = some relevance, 100%=maximum relevance)
Reliability: data/information	Information - trusted/proven source, new/unproven source; Computer - Mean-Time Between Failures (MTBF), ID faults to board level 95% accuracy;
Reliability: system	The probability a system will perform satisfactorily for a period of time under a set of conditions. Metric is a percentage scale (0%=not reliable, 50%=somewhat reliable, 100%=highly reliable).
Reliability: individual decisions	Measures the reliability of the decisions made by an individual over a period of time under a set of conditions. Metric is a percentage scale (0%=not reliable, 50%=somewhat reliable, 100%=highly reliable)
Reliability: collaborative decisions	Measures the reliability of collaborative decisions made by a team of individuals over a period of time under a set of conditions. Metric is a percentage scale (0%=not reliable, 50%=somewhat reliable, 100%=highly reliable)
Robustness	Ability to maintain effectiveness across a range of tasks, situations, and conditions across a range of missions that span the spectrum of conflict. Metric would be a percentage scale (0%=no robustness, 50%=some robustness, 100%=maximum robustness)
Shared Awareness	Shared awareness is the human perception of the situation as it is and as it is becoming. The elements of military situations include: physical environment, the capabilities and intentions of red, blue, and other forces and effectors, and the political, military, social, economic, and information contexts.
Shared Understanding	Shared understanding is the recognition of patterns, cause and effect relationships, dynamic futures, and opportunities and risks that are shared between individuals, organizations, or other entities.
Situational Awareness	Situational awareness is the "who's", "where" category. It includes friendly, enemy, and neutrals location, status; vulnerabilities and capabilities. It also includes weather and terrain features. For targeting it includes detect, locate, ID, track, and display.
Situational Understanding	Situational understanding is the "what does it mean?" category. It includes understanding of enemy intent, likely and dangerous courses of action, and actions. It includes the assessment of friendly opportunities for favorable actions and the associated risks. Situation understanding also includes resolving and dealing with uncertainty.
Speed of Command	Measures the time lag between an occasion for action and the implementation of action or a decision not to respond.
Speed of Decision	Measures the amount of time it takes for a decision to be made beginning with the time a need for some action (or decision not to act) is identified through the time where a decision is made.
Strike or Attack Mission Cycle Functions	Detection, location, identification, decision, execution, assessment.
Survivability: data/information	Measures the ability of data/information to survive and operate in various environments. Measurement is a percent scale (0%=not survivable, 100%=totally survivable).
Survivability: network	Measures the ability of the network to survive and operate in various environments (at least one complete path). Measurement is a percent scale (0%=not survivable, 100%=totally survivable).
Synchronization: Actions	Degree to which actions are synchronized. Metric is an synch action level (0%=no synchronization, 100%=maximum synchronization) or synchronization interval (95%, 90%) of actions

FACTORS CRITERIA	CHARACTERISTICS/EXAMPLES
Synchronization: Decisions	Degree to which decisions are synchronized. Metric is an synch decision level (0%=no synchronization, 100%=maximum synchronization) or synchronization interval (95%, 90%) of decisions
Synchronization: Entities	Degree to which entities are synchronized. Metric is an synch entity level (0%=no synchronization, 100%=maximum synchronization) or synchronization interval (95%, 90%) of entities
Synchronization: Plans	Degree to which plans are synchronized. Metric is an synch plan level (0%=no synchronization, 100%=maximum synchronization) or synchronization interval (95%, 90%) of plans
Timeliness: data/information	Measures the utilization of the data/information as a function of time. Metric is an ordinal scale (0=no match between currency level needed and what is available, 10=high degree of matching between currency level needed and available
Timeliness: shared data/information	Measures the utilization of the shared data/information as a function of time. Metric is a percentage scale (0%=no match between shared data/information needed and what is available, 50%= some degree of matching between shared data/information needed and what is available, 100%=high degree of matching between shared data/information needed and available.)
Timeliness: shared awareness	Measures the utilization of the shared awareness as a function of time. Metric is a percentage scale (0%=no match between shared awareness needed and what is available, 50%= some degree of matching between shared awareness needed and what is available, 100%=high degree of matching between shared awareness needed and available.)
Timeliness: shared understanding	Measures the utilization of the shared understanding as a function of time. Metric is a percentage scale (0%=no match between shared understanding needed and what is available, 50%= some degree of matching between shared understanding needed and what is available, 100%=high degree of matching between shared understanding needed and available.)
Trust: Peer-to-Peer	Measures the extent of trust between entities that are at the same level. Metric is a percentage scale (0%=no trust, 50%=some trust, 100%=significant trust)
Trust: Supervisor-to-Subordinate	Measures the ability of a supervisor to demonstrate trust in a subordinate by a willingness to delegate and allow subordinates to work without constant supervision. Metric is a percentage scale (0%=no trust, 50%=some trust, 100%=significant trust).
Trust: Subordinate-to-Supervisor	Measures the extent of trust to which a subordinate has with its supervisor. Metric is a percentage scale (0%=no trust, 50%=some trust, 100%=significant trust)
Trust: data/information	Measures the extent of trust to which an entity is willing to rely on the data/information. Metric is a percentage scale (0%=no trust, 50%=some trust, 100%=significant trust)
Trust: Organization	Measures the extent of trust to which an organization is willing to rely on other organizations. Metric is an ordinal scale (0=no trust, 5=some trust, 10=significant trust)
Trust: System	Measures the extent of trust of the system by individuals and/or organizations. Metric is a percentage scale (0%=no trust, 50%=some trust, 100%=significant trust)
Uncertainty: shared awareness	Measures the confidence level (0%=uncertain, 100%=certain) or confidence interval (95%, 90%) of shared awareness
Uncertainty: shared understanding	Measures the confidence level (0%=uncertain, 100%=certain) or confidence interval (95%, 90%) of shared understanding
Understanding	Understanding is defined as the process state of drawing inferences about possible consequences of the operational situation. It is based on the ability of the battlestaff acting individually and collaboratively to predict possible future patterns of the battlespace. That is, whereas awareness deals with the battlespace as it was, understanding deals with the battlespace as it is becoming. Interpreting these patterns spatially, functionally, temporally in the context of the goals/objectives, constraints, and planned courses of action envisioned for the operation, the battlestaff begins to identify potential threats and opportunities that demand a response change or decision from the command authorities.

Appendix D: Subjective Logic (Denny, 2010, Paper 113)

Subjective reasoning is based purely on one personal beliefs, ideals, preference opinion or culture. For example when you watch the news and see a story about incest, one might be offended at the very thought while others would not be as shocked because it is "natural" for their way of life. Like some religious sects have incestual marriages and believe it is right where others do not. These are examples of subjective reasoning.

Subjective Logic (Josang, 1997) (Josang, 2009) is a type of probabilistic logic that is often used in evidential reasoning where belief (b), disbelief (d), and uncertainty (u) must be explicitly and simultaneously accounted. In contrast to systems described by Boolean Logic, for those systems described by Subjective Logic the basic object is an opinion rather than a fact. An *opinion* $\omega A(x)$ about some proposition "x" held by source "A" is a 4-tuple of the belief (b_x^A), disbelief (d_x^A), uncertainty (u_x^A), and relative atomicity (a_x^A)[12]. Mathematically, it is not necessary to specify all three of the values; however, the sum of the values always equal one ($b_x + d_x + u_x = 1$).

Subjective Logic algebra provides an array of operations that can be used to manipulate opinions. These operators have many applications in evidential reasoning and data fusion. The consensus operator (written as) is used for belief fusion, providing the capability to fuse possibly conflicting opinions while still forming coherent, summary judgments. The underlying calculations on the belief tuple elements are given in Figure D-1.

$$K = u_x^A + u_x^B - u_x^A u_x^B$$

$$b_x^{A,B} = (b_x^A u_x^B + b_x^B u_x^A) / K$$

$$d_x^{A,B} = (d_x^A u_x^B + d_x^B u_x^A) / K$$

$$u_x^{A,B} = (u_x^A u_x^B) / K$$

$$a_x^{A,B} = (a_x^A u_x^B + a_x^B u_x^A - (a_x^A + a_x^B) u_x^A u_x^B) / (K - u_x^A u_x^B)$$

Figure D-1: Subjective Logic Consensus Operation (Denny, 2010, Paper 113)

Subjective logic also provides a well developed "discount" operation (written as) that can be used for modifying the contribution of evidence based upon a subjective measure of confidence in the source of the evidence. The discount operator thus provides a rather general means of describing degrees influence and can be used to represent semantic similarity, relevance, trust, etc. The calculations for implementing a discount operator over belief tuples is shown in Figure D-2.

[12] Atomicity is the base-rate of the proposition.

$$b_x^{A,B} = b_B^A \, b_x^B$$

$$d_x^{A,B} = b_B^A \, d_x^B$$

$$u_x^{A,B} = d_B^A + u_A^B + b_B^A \, u_x^B$$

$$a_x^{A,B} = a_x^B$$

Figure D-2: Subjective Logic Discount Operation (Denny, 2010: 4)

An algorithm can be established to measure the bias to a situation as shown in Figure D-3. (Denny, 2010: 13)

Algorithm 1: Assign bias to situation elements:
For each **SituationElement**, *e*:
Instantiate **Impact** statement, *i*, that refers to *e*.
Instantiate **Conviction** statement, c_i, set to (the default) ignorance (b=0, d=0, u=1.0)
Set *i* to refer to *c*

Algorithm 2: Fuse propagation paths into Impact accumulator
for each **Judgment** *j* (where the author of *j* is not "ARID"):
if *j.about*, is of type **SituationElement**; then...
get **SituationElement** *e* to which *j.about* refers
for each **Propagation** *p* that refers to *e*:
get the **Impact**, *i*, associated to *e*
let *cp* be the **Conviction** of the *p*
let *ci* be the **Conviction** of the *i*.
accumulate *cp* into *ci* by consensus*: ci* ← *ci* ϕ *c*p

Algorithm 3: Back propagate influence to supporting evidence
for each **Evidence** statement, *s*:
let *j* be the **Judgment** that *s* supports
let *cj* be the **Conviction** of *j*
let **SituationElement** *e* be evidence of *s*
let *i* be the **Impact** of *e*
let *ci* be the **Conviction** of *i*.
let *d* be the strength of *s*
accumulate cj into ci: ci ← ci ϕ *(d* ϕ c_j*)*

Bibliography

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Dr. Phister is the Chief of the Special Programs Division at the AF Research Laboratory's Information Directorate headquartered in Rome, New York. Dr. Phister spent 25 years in the military (Lt Col, retired) where he worked primarily in space systems development and operations. Dr. Phister is a recognized subject matter expert in information technologies, C2, net-centric warfare and space operations. Over the past two decades, Dr. Phister has published 35 technical publications and has served as technical chair at numerous C2 conferences. Dr. Phister holds two Masters Degrees (Electrical Engineering and Systems Management), a Ph.D in Engineering as well as four AF Acquisition Level-3 certifications (Program Management, Test and Evaluation, Systems Engineering, and Systems Engineering-Manager). Dr. Phister is a senior member of both AIAA and IEEE and holds a dual engineering license in software and electrical engineering from the State of Texas.


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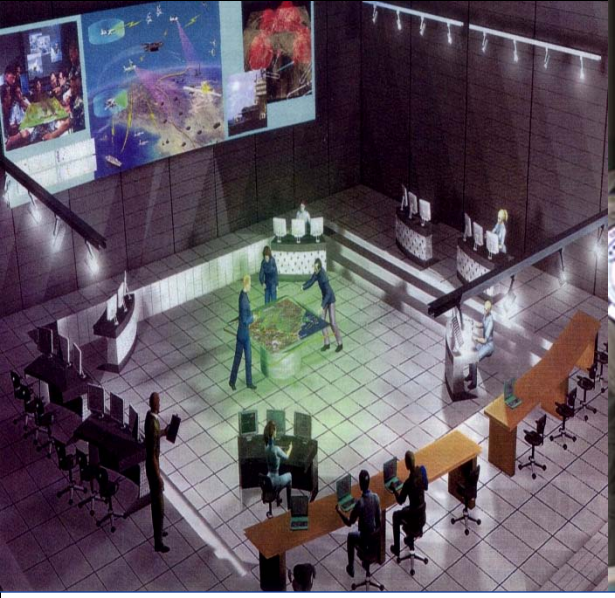

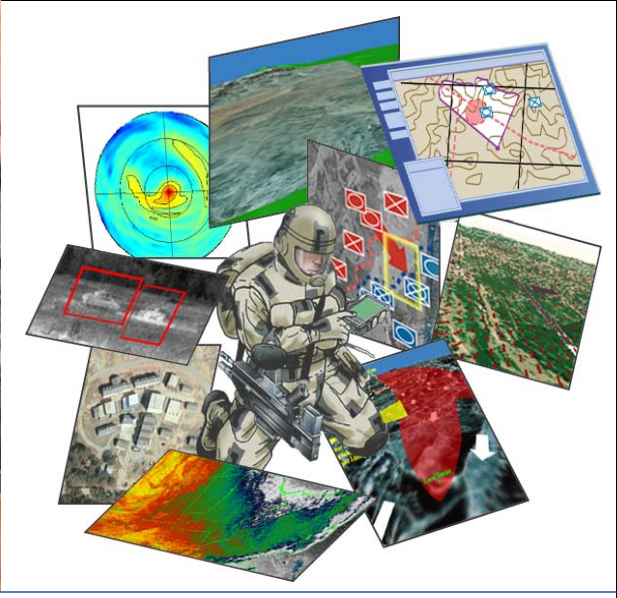

Mission Effectiveness: Proposed Nth-Order Taxonomy
-- Concepts, Theory, and Policy --

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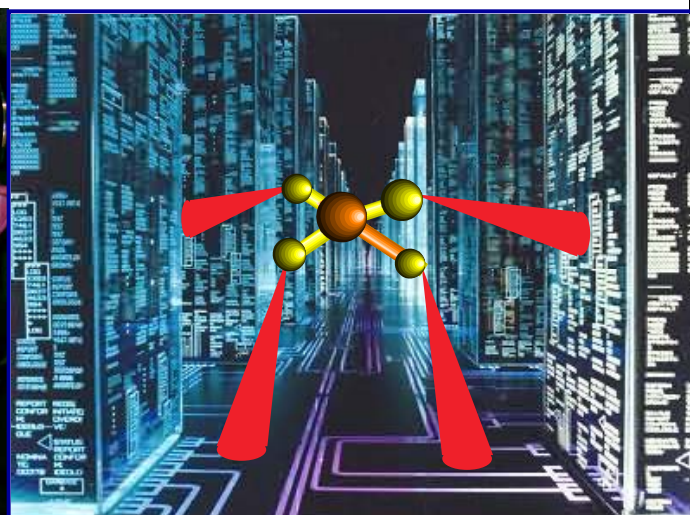
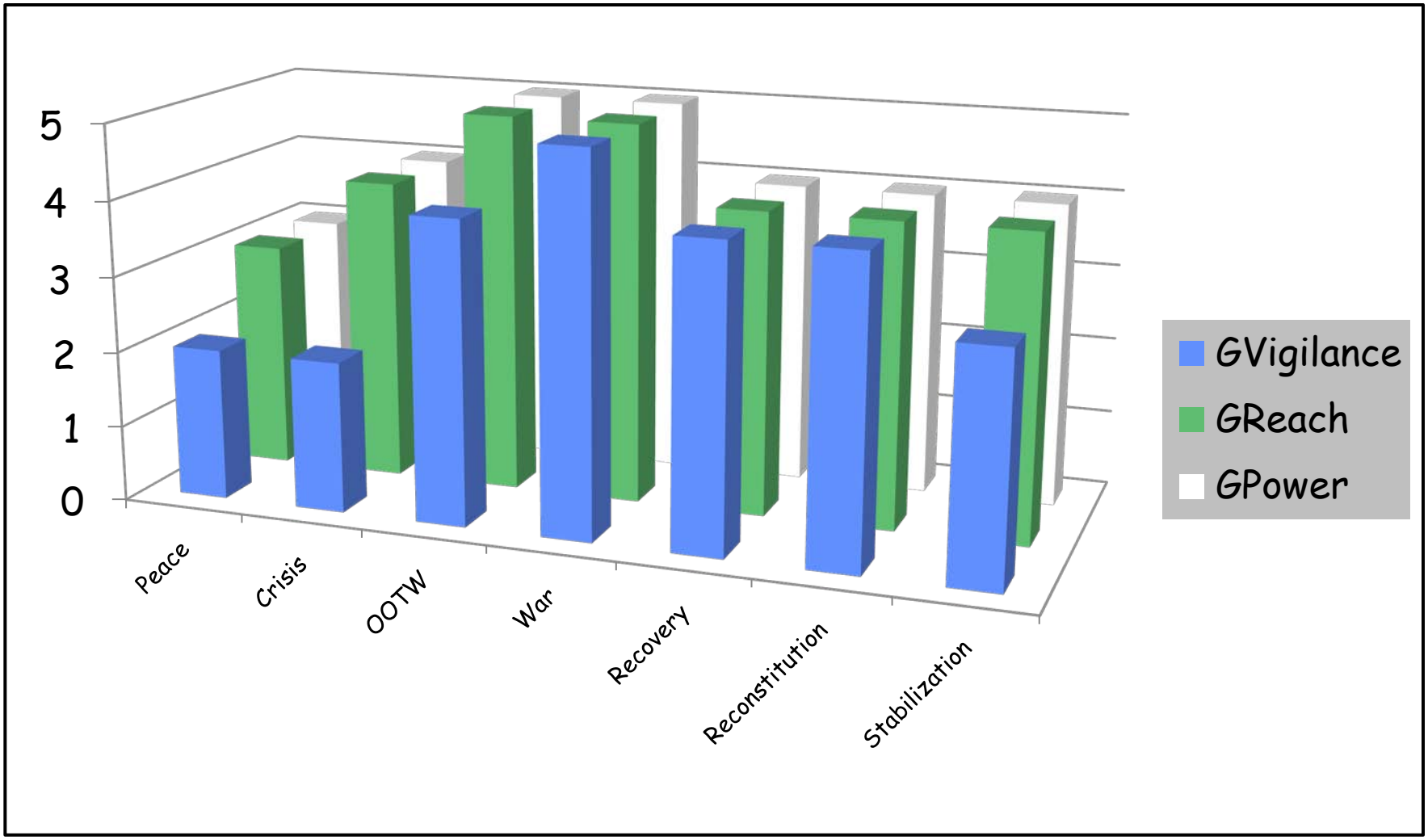
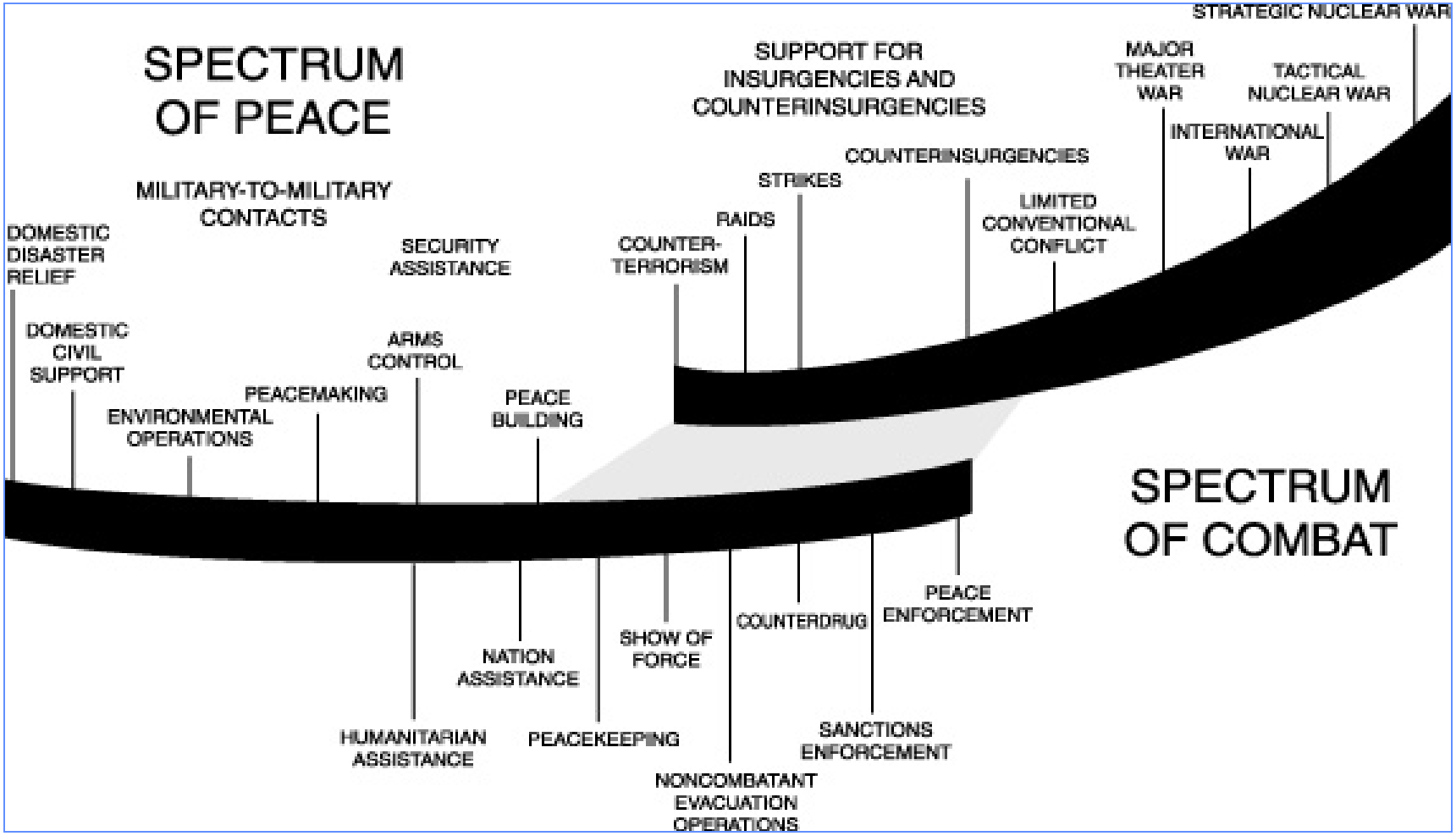


Phases of Conflict

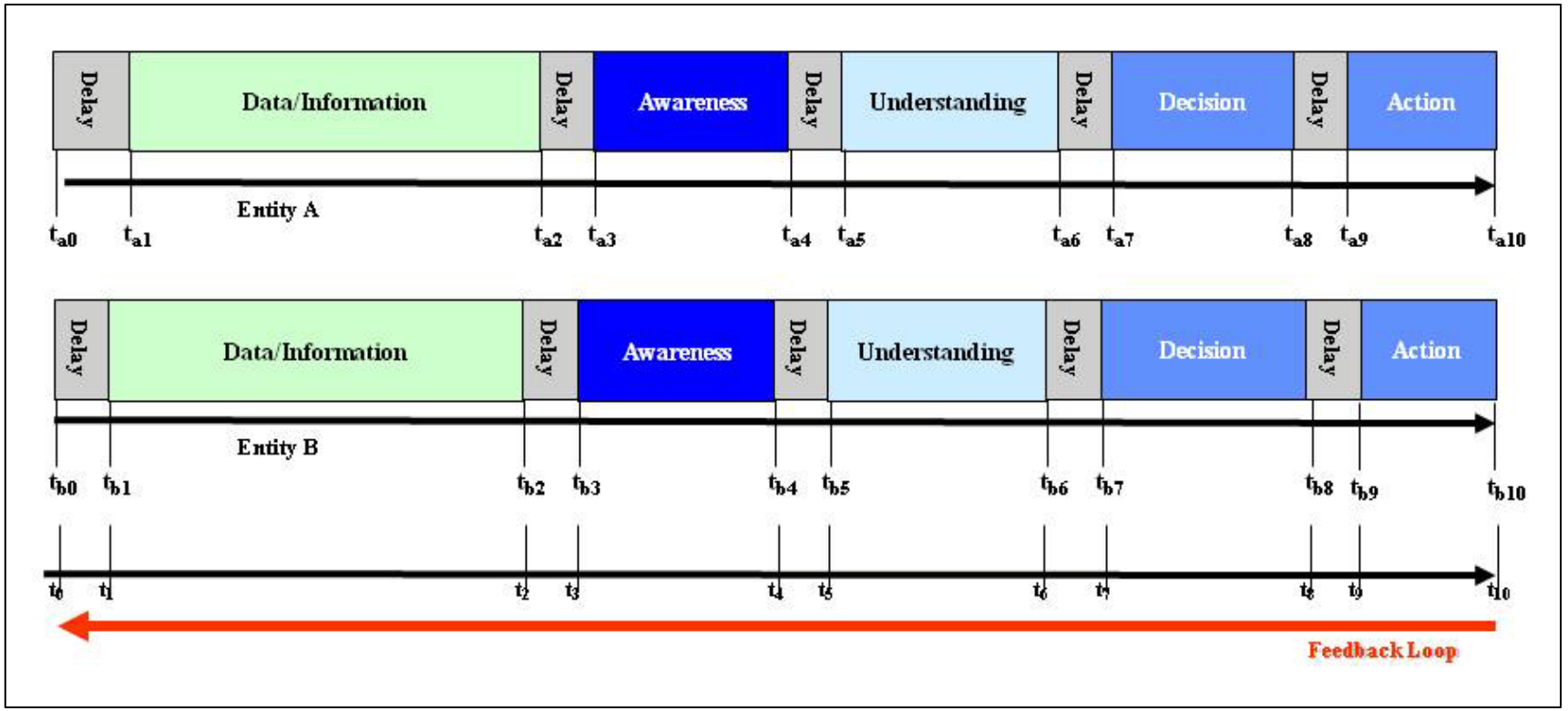
- Global Vigilance, Reach and Power -



Span of a Complex Endeavor



Network Centric Warfare
- Operational Timelines -



Metrics:

----------→Time to Collect Data

----------→Time to Awareness

----------→Time to Understanding

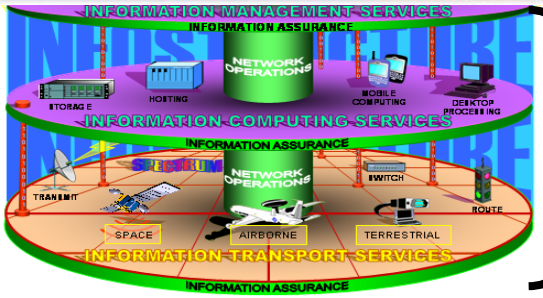
----------→Speed of Command

----------→Speed of Action

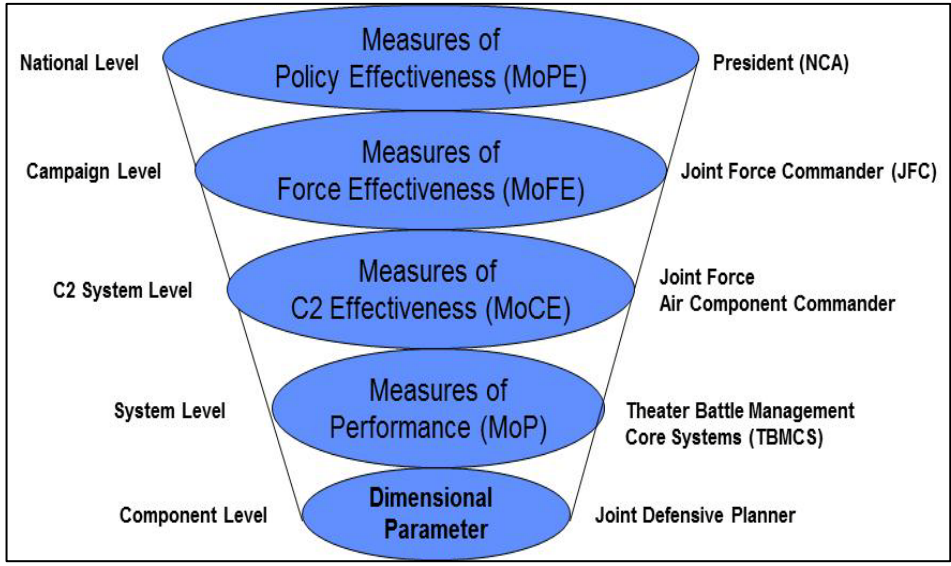
Network Centric Warfare

- Measures of Effectiveness -

Network Centric Operations



Network Centric Infrastructure



Metrics: Political, Diplomatic, Military, Economic, Social, Information, Infrastructure

Proposed Nth-Order Taxonomy

- Strategic - Tactical – Operational -

Nth Order	Description	Level	Area	MOPs/MOEs
0	Actual Event	Tactical	Local	
1	Desired Effect	Tactical	Local	DP
2	Collateral Damage (Physical)	Tactical	Local	DP
3	Collateral Damage (Non-Physical)	Tactical	Local	DP
4	C2 Systems Effectiveness	Operational	Regional	MoCE
5	Command Intent Effectiveness (e.g., JFACC, JFLCC, JFMCC)	Operational	Regional	MoFE
6	Command Intent (JTF) Effectiveness	Operational	Regional	MoFE
7	National ROE/Policy Effectiveness	Strategic	Global	MoPE
8	Coalition ROE/Policy Effectiveness	Strategic	Global	MoPE
9	International ROE/Policy Effectiveness	Strategic	Global	MoPE

Mathematical Representation
- Proposed Nth-Order Taxonomy-

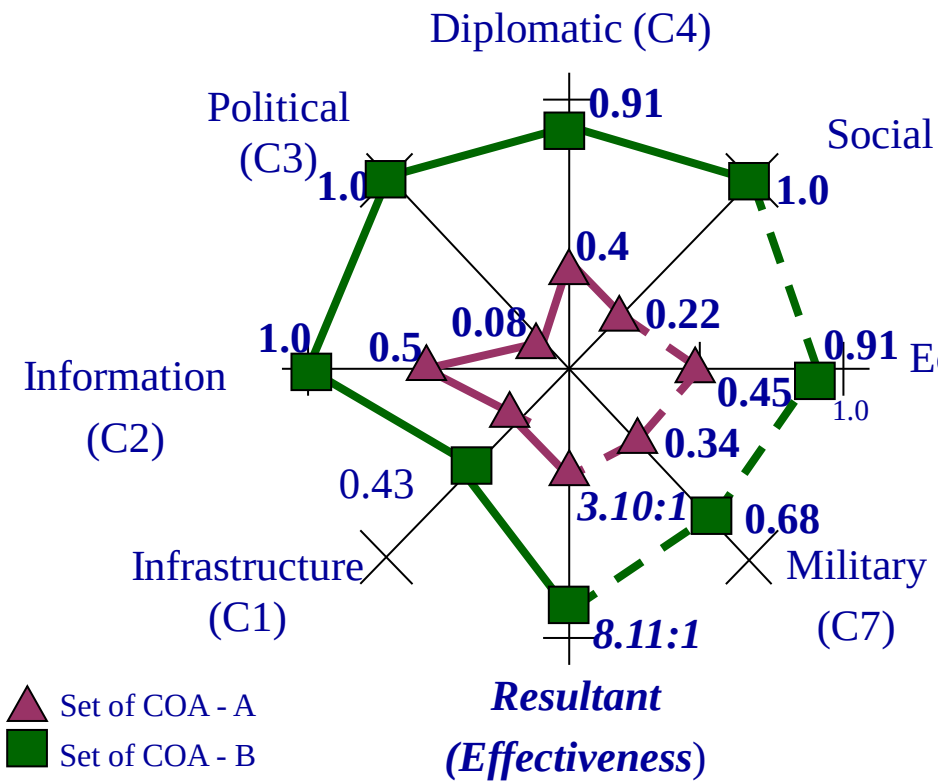
MOE (cyber agility) = f(belief) + f(disbelief) + f(uncertainty)

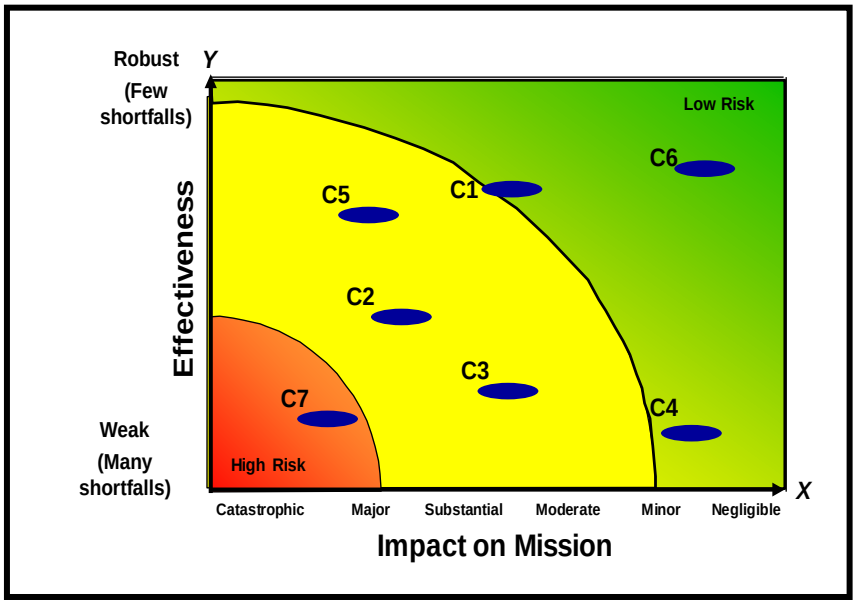
Scoring Metric:

0.00 = Detrimental to Mission Operations,
0.25 = Unacceptable to Mission Operations,
0.50 = Acceptable to Mission Operations,
0.75 = Very Acceptable to Mission Operations,
1.00 = Significantly Acceptable to Mission Operations

Denny, Nathan,
"Mission Profiles and Evidential Reasoning for Estimating Information Relevancy in Multi-Agent Supervisory Control Applications,"
15th ICCRTS, Paper 113, June 2010, page 4, 10, and 13.

Mathematical Representation
- Proposed Nth-Order Taxonomy Analysis -

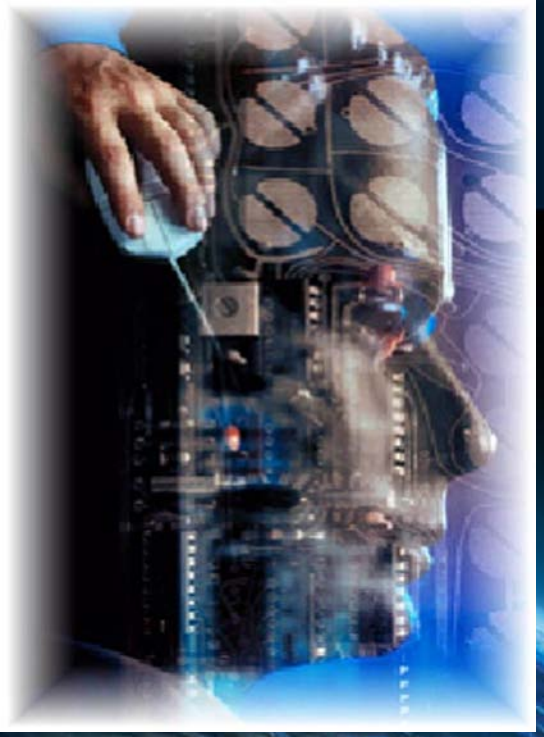




Conclusions

- Need to Plan / Assess Operations within a Complex Endeavor
- Combine PEMSII and DIME into Proposed Nth-Order Taxonomy:
  - Political, Diplomatic, Military, Economic, Social
  - Information, Infrastructure
- Proposed Nth-Order Taxonomy
  - Incorporates Net-Centric Operations
  - Incorporates Strategic, Tactical, Operational Factors
- Provides consistent in-depth analytical capability
  - Indicating 7th-Order effect (National ROE/Policy Effectiveness) will convey consistent context

Goal is to conduct robust analysis in developing COAs



Questions?

AFRL “Inside”